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F-18 INTERIOR LIGHTING ANALYSIS: RED vs. WHITE

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This report presents a brief summary of the literature relevant to the selection of cockpit lighting coloration for the F-18 (and similar) aircraft. The generally accepted preference for red lighting is questioned with the ultimate choice of color found to rest upon a mission requirement for maximum sensitivity for light detection.

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INTRODUCTION

In many current and future weapon systems, the increased employment of new sensor/display systems (LLTV, radar, infrared, etc.) for aircrew information acquisition, the computer processing of multi-variate data, the highly integrated presentation of very complex tactical/strategic situations, and new methods of system selection and control, have considerably altered the traditional visual man-equipment information transfer that existed in previous air weapon systems. Therefore, the cockpit instrument lighting requirements and design criteria established in previous studies cannot be directly applied to cockpits incorporating these new systems or subsystems. These new subsystems and their integration in new aircraft greatly extend the human sensory, motor, and mobility range and provide an ever increasing amount of aircraft/environmental information and the resolution of the flight/tactical dynamics which would otherwise exceed human capabilities. In these weapon systems, the aircrew will still have to effectively interface with the various subsystems to insure mission fulfillment under both day and night operational conditions. During night operations, the human eye will continue to play an important role in external visual tasks in almost all flight missions. Accordingly, it is essential that effective crew station lighting design criteria/requirements which are specific to these new subsystem configurations be established to insure a maximum potential for effective night vision and thus for aircrew mission fulfillment. In the F-18 aircraft development, which represents a weapons system development accompanied by the above problems, major considerations of the interior lighting design to provide optimum utilization of aircrew capabilities during the varied flight operations is very appropriate.

It is the purpose of this report to:

1. Review a selection of the pertinent medical, human factors, lighting, and visual literature.

2. Present any available data on the relative merits and costs of red and white lighting.

3. Where appropriate, provide a rationale for the selection of color for the interior lighting to be employed in the F-18 aircraft.

BACKGROUND

VISUAL CHARACTERISTICS

There are several basic characteristics of the human visual system which must be considered in evaluating the question of what lighting color to use. The first is that the human eye contains two types of receptors: the scotopic (rods) and photopic (cones) as shown in figure 1. The second is that the rods can detect light sources at intensities up to 100 times less bright than those required for detection by cones (figure 2). It must be kept in mind, however, that the key word in interpreting these sensitivity curves is "detection". It is not uncommon to hear the rods mistakenly referred to as the night vision receptors and the cones labeled as the receptors for daylight vision. Though the rods can detect the presence of light sources below the level of photopic (cone) vision, they are

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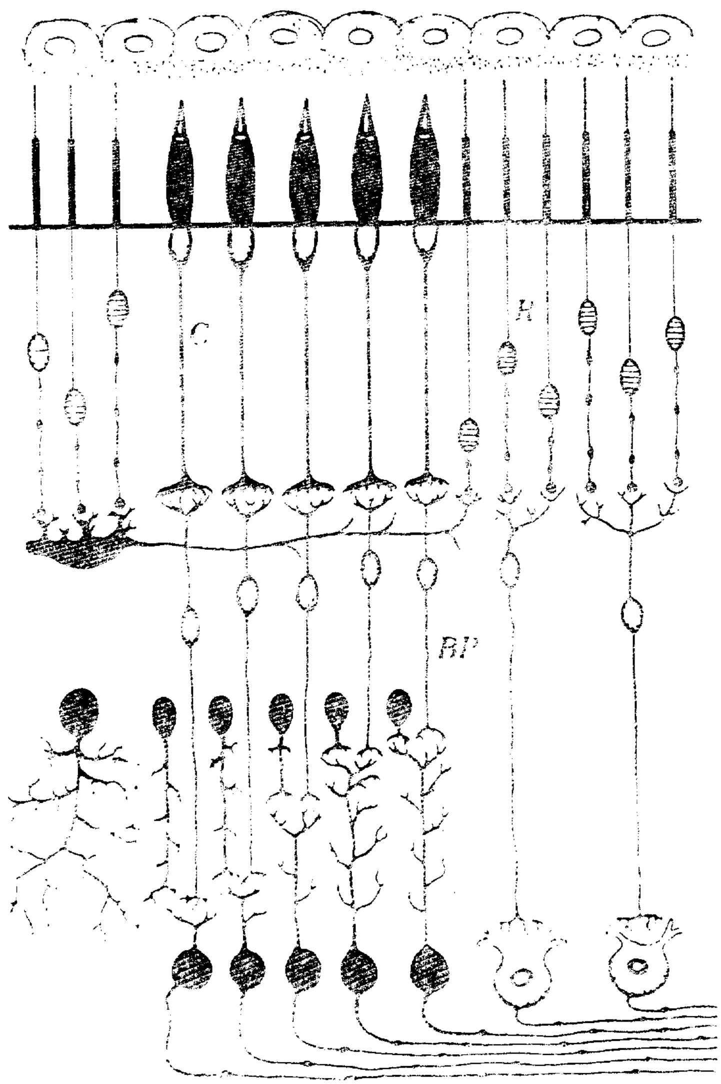

Figure 1. Detailed structure of the retina. The cones, C, are connected individually by bipolar cells, BP, while the rods, R, show multiple connection.

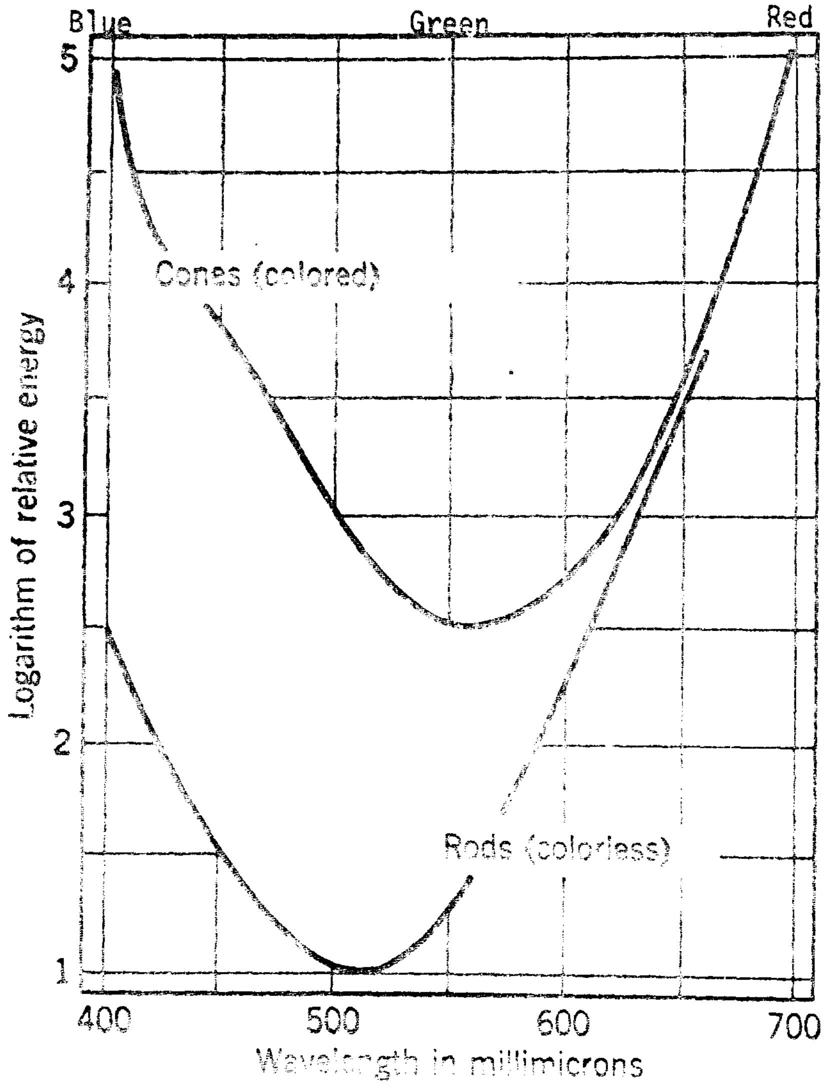

Figure 2. Spectral sensitivity curves for rod and cone vision, showing the relative energy required to produce a threshold response. The actual energy increment above the threshold for the appearance of color (cone function) varies for different parts of the retina. In the parafovea it is between 0.1 and 1.0 log unit. The distance between the two curves represents the *photochromatic interval*. (Hecht and Yun Hsia, 1945.)

virtually useless for "seeing" in the sense with which we ordinarily use that term. This is true for several reasons. First, a number of rods frequently share a common optic neural fiber (figure 1). While the serial, or summation, effect obtained by "ganging" the receptor rods may well explain their increased sensitivity, it is obvious that it greatly reduces their resolution capability when compared with the one-to-one receptor/neuron relationship of the cones. Also, the rods do not resolve colors which further degrade their discrimination and information acquisition capability. Probably the most important factor determining the limitation of rods as receptors for visual information can be seen by reference to figure 3 which shows that there are virtually no rods in the foveal area, only cones. Since most of the activity which we generally call "seeing" requires foveal tracking of an object of interest, such activities must depend primarily upon cones, not rods. In detecting dim light sources, it is common to catch a glimmer "out of the corner of the eye" (using the periphery of the retina where rods are plentiful), only to have the source vanish when the observer "looks at it" (focuses it upon the fovea containing only less sensitive cones). This "macular blindness" is why observers are trained to "sweep search" at night to maximize the chance of catching a dim source with the peripherally distributed rods. Rod vision <u>can</u> detect extremely dim light sources, particularly if they are off-boresight for the eye and/or are "moving" (either on their own or due to observer head motion), and can perceive gross imagery which subtends a visual angle of perhaps 10° or more (such as the horizon, large land masses, and/or gross terrain contours). However, rod vision <u>alone</u> cannot meet the visual requirements for such missions as night time air-to-ground weapons delivery which require pattern discrimination (target recognition), directionality (relative bearings), distance perception (range), and/or rates of relative motion. All of these visual activities depend principally upon binocular foveal tracking and, therefore, require sufficient external illumination to excite the cones. Thus it is clear that the value of red cockpit lighting to most missions rests not upon its protection of the dark adaptation of the relatively uninformative rods but upon its failure to overlap, and thus degrade by light adaption, the primary spectral sensitivity of the cones. As shown in figure 4, the standard red filter not only protects 99 percent of the spectral range of the rods but 90 percent of the spectral range of the cones as well. It is this 90 percent protection of the cones which contributes the most to maintenance of cone sensitivity and thus to what is usually meant by "night vision".

HISTORY OF COCKPIT LIGHTING

Since a number of studies (Hartline, et al, 1941; Hecht and Hsia, 1945; Rowland and Aloan, 1944; Webster and Lee, 1942) supported the hypothesis that red lighting was advantageous for acquiring and maintaining night vision at useful levels of display luminance, the U.S. Navy during World War II adopted a system using red lighting for crew stations in all aircraft and ships. In the fall of 1949, the U.S. Navy and the U.S. Air Force cooperated in conducting an evaluation tour at selected operational bases to gather opinions from Navy and Air Force pilots on their subjective preferences for the Navy red lighting and ultraviolet lighting systems (the lighting system used by the Air Force at that time). Similar military aircraft equipped with the best designed red/ultraviolet light systems were flown by a large cross section of Navy and Air Force pilots. As a result of this subjective evaluation, the red lighting system became standard for all services. In 1959, the U.S. Air Force adopted a new blue-white lighting system for specific

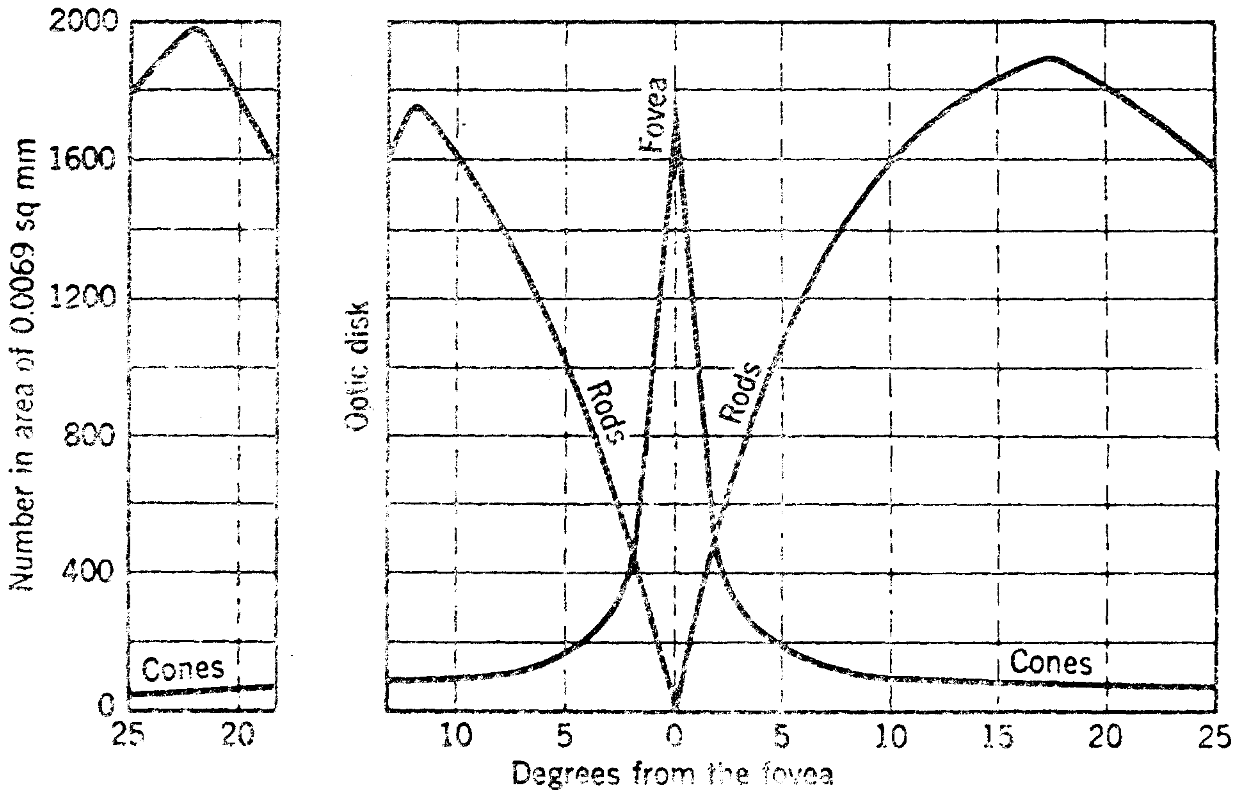

Figure 3. Diagram to show the number of receptors (cones and rods) at various distances from the fovea. The number of cones drops rapidly with increasing distance from the fovea, and the rod density times. (Osterberg, 1935.)

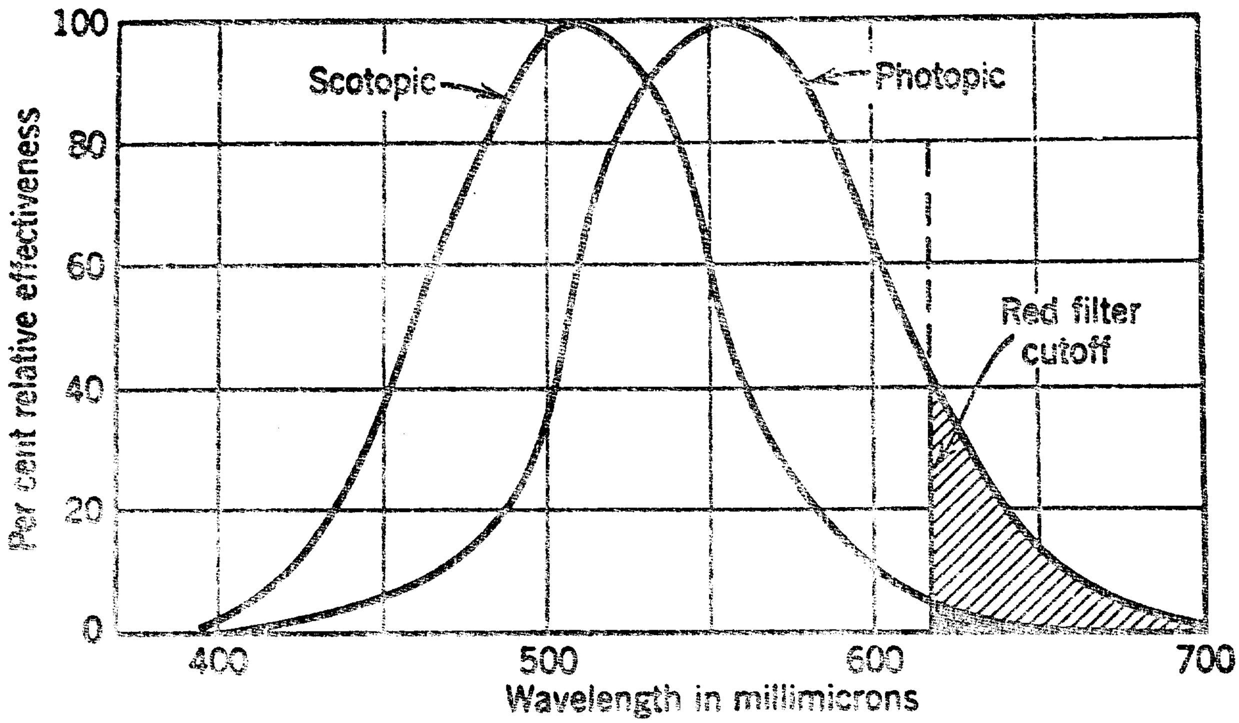

Figure 4. Luminosity curves for scotopic (rod) and photopic (cone) vision. Since the maxima are arbitrarily set at 100, these curves give no information about the relative sensitivity of the rods and cones. The vertical line indicates the place at which a common red filter cuts off. It transmits 1/10 of the light involved in the cone curve, and 1/100 of that in the rod curve. (Hecht and Yun Hsia, 1945.)

aircraft in which aircrew external visual duties did not include requirements for high levels of night vision, and the use of color coding could be employed in the newly adopted vertical scale type flight and engine displays. The Navy and Army have continued to use red lighting in all crew stations where the aircrew has visual tasks which require high level night vision (figure 5).

BASIC COCKPIT LIGHTING DESIGN CRITERIA

The designer of aircraft interior lighting systems must be aware of the interrelationships of visual and engineering variables in order to design lighting which will produce operationally efficient and effective crew station environments for day, and especially, night operations. The requirements in current lighting specifications are based on the above interrelationships. In addition, the following limitations have been formulated and utilized as criteria in the design of recent crew station lighting:

1. There should be a minimum of specular reflections or direct view of the light sources which would not only affect night visual capability, but would also act as glare sources effecting both internal and external aircraft vision.

2. There should be a minimum of illuminance and luminance variation among control console areas and display or among markings in any crew station area. At the low levels of lighting to be employed, it would be undesirable to have some of the markings below the threshold of legibility or even at greatly differing supra-threshold visibility levels.

3. The luminance level should be adjustable and provide achievement of the <u>operationally required</u> night visual state. In addition, some provision must be made to reduce or eliminate the illuminance of controls displays to those only essential for each operating condition.

4. The luminance contrast between illuminated elements and backgrounds should not be so low as to give rise to visual illusions (i.e., autokinesis).

5. The lighting system should be reasonably rugged and not too complex for ease of installation and servicing. Obviously, it should not interfere with the functioning of the instruments or controls and should be as economical in terms of cost, power, consumption, and maintenance requirements as possible.

6. The lighting system should place minimal demands upon, and be fully acceptable to, the pilot population as well as providing the pilot with a sense of confidence that he can accomplish the mission required of him.

7. Finally, the lighting system should take into account all of the potential luminance sources within the internal and external visual environments.

RED VERSUS WHITE LIGHTING

The question of RED versus WHITE Lighting will be discussed with respect to each of the previously outlined design criteria.

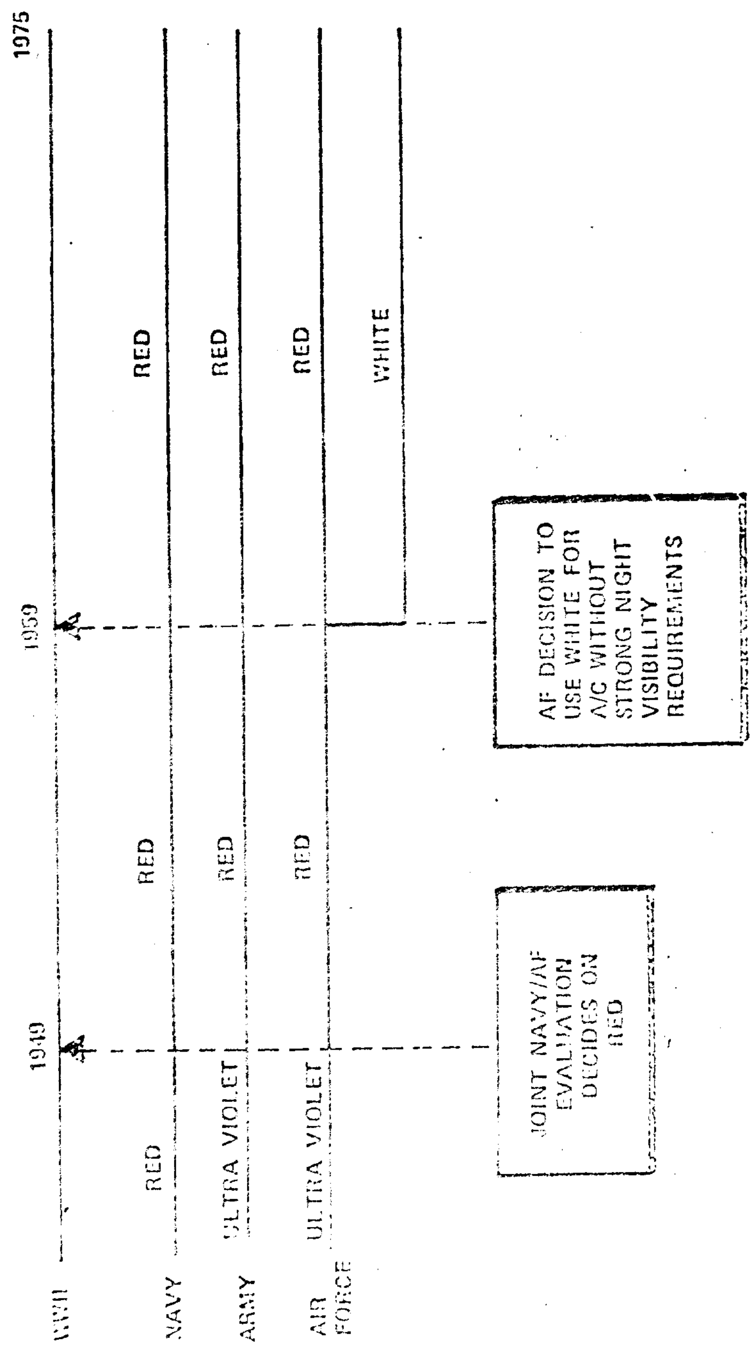

Figure 5. Graphic History of Cockpit Lighting.

1. Reduction of Glare and Reflections. The shape of the canopy, the placement of lights, and the presence of an instrument panel sunshield in the modern jet fighter place the highest probability for glare and/or reflections in the areas on either side of the pilot where they would most likely be picked up by peripheral vision. Since peripheral vision predominantly involves the rods which are 99 percent insensitive to the MIL-L-18276 specified red illumination, the likelihood that the pilot will perceive and/or be distracted by the reflections of red lit instruments and consoles is less than if they were lit by white lamps. In addition, if anti-reflection coatings prove to be necessary, it is far easier and less expensive to incorporate existing monochromatic coating for the narrow spectral band of red light than to develop new coatings for the broader spectrum of white light. Also, red, anti-reflective coatings are far less likely than white coatings to interfere with or degrade daylight out-the-window viewing.

2. Uniform Display Luminance. The resultant luminance of any display (other than those possessing self or activated luminous qualities) is a function of both the spectral nature of the luminance and the reflectance characteristics of the display surface. White light is produced by radiant energy which includes all colors, while aviation red light is confined to energy above 580 millimicrons. Thus, from a quality control standpoint, the spectral reflectance of the white characters among the various displays must possess almost identical spectral reflecting qualities or the resultant appearance of the total display will be very non-uniform under white lighting conditions. If a spectrally controlled white light (such as blue-white) is used, these color and luminance discrepancies will be even more apparent. Under monochromatic lighting conditions (particularly red), such color differences are far more difficult to perceive and any spectral/reflectance differences due to non-uniformity will be seen only as minor differences in luminance and not as wide color variations. Since our initial quality control in the spectral reflectance of display colors allows a chroma tolerance and climatological effects produce variance in this reflectance characteristic, it can be predicted that greater apparent uniformity in display luminance can be obtained and maintained over wider range of brightness under red rather than white lighting conditions. A study of Air Force white and red lighting by Dohrn, 1967, revealed that a problem does indeed exist in this area. He stated: "The distribution of light over single instruments or groups of instruments shows extreme gradations for the cockpits studied". Since a single unnecessarily bright instrument light may have the same detrimental effect as an entire instrument panel on the pilot's level of dark adaptation, it is important that the luminance of individual instruments be balanced and evenly distributed. It was concluded that "there is a definite need to evaluate and upgrade the quality of instrument lighting". This required level of quality control could be more easily achieved with red than with white lighting though some improvement has been achieved in the uniformity of white lighting since the Dohrn study. Even if red light is chosen, the specifications for what is an acceptable "Red" are not in agreement (Farnsworth and Hillmann, 1953).

3. Achievable Night Vision in Accordance with Mission Requirements. To accomplish any night time mission, the pilot must be able to "see" (obtain information visually) within the cockpit. He may or may not be called upon to also obtain information from outside the cockpit depending upon the nature of the mission. That different missions, or mission segments, do indeed impose different external visual requirements have been described by Burns and Ziegler, 1960, and empirically quantified in a study by DeBruine and Milligan, 1971, in which they measured the level of cockpit instrumentation illumination selected by pilots during segments of night time practice missions. Their findings

are summarized in figure 6. Assuming that the lower the internal illuminance settings, the greater the need for out-of-the-window night vision, it can be seen that their data confirm the expected by showing that the external visual adaptation demands assessed by the pilots are minimal for take-off, more stringent for low-level cruise and climb-out, and maximal for dive bombing. They also confirm the need for differential control of the illuminance of various instruments, based upon mission segment. However, as might well be expected, visual requirements during some mission segments conflict; if they did not, the whole question of Red vs. White would most likely have been resolved long ago. While the DeBruine study showed pronounced out-the-window visual requirements for low-level cruise, which implies a need for red lighting during this mission phase, a corollary requirement, map reading, has been found to be seriously degraded by the loss of color coding experienced under red illumination (Chisum, 1967; Crook, 1954). The same finding would hold true for moving map display systems using standard aerial chart topographical formatting. Though Crook, 1954, has proposed techniques for modifying charts to alleviate this readability problem, the use of new charts would constitute an entirely new logistic support requirement and expenses for the F-18.

Under reduced illumination conditions, the pilot must still accurately read the legends and displays within his cockpit. Though there is some controversy regarding relative acuity under red and white lighting conditions under intermediate levels of illumination, it is generally agreed that red light yields the best acuity at the lower levels of incandescent illumination (Brown, 1957; Brown and Grether, 1952; Chapanis and Halsey, 1955; Grether and Reynolds, 1967; Intano, 1967; Luria and Shartz, 1960; Reynolds, 1971). However, the definition of "red" appears to be important. Research by Cavonius and Hilz, 1970, indicates that recovery of detailed discrimination is accelerated by the use of light of approximately 600 millimicrons wavelength (orange) rather than the deeper red currently used.

Nighttime formation flight is sometimes cited as posing a requirement for optimum external vision. Though this was true when the only cues available were the aircraft out-line and running lights, the F-18 (like the F-14) will be equipped with electroluminescent side panels which provide adequate position and attitude cuing even to the relatively unadapted eye. In addition, these panels unlike wing lights, are not visible from the ground. Therefore, formation flight can be eliminated as a basis for selection of internal lighting color (Reising, 1975) unless the F-18 will be called upon to fly formation with older A/C not equipped with side panel formation lights.

Another visual task area pertinent to the F-18 is nighttime carrier operations. Kennedy and Berghage, 1965, report that: "The night accident rate for carrier landings is five times the day rate. This raises the possibility that visual errors caused by lack of dark adaptation may be involved". In contrast to the findings of DeBruine and Milligan, which showed dark adaptation requirements to be the least (for the Air Force pilots) during the take-off phase, the Kennedy study also reported that "The greatest value to an aviator (during carrier operations) of being adapted to the dark...was during launch". In summary, however, the value of dark adaptation to nighttime carrier operations was not conclusively established with the Kennedy study further stating: "Completed questionnaires regarding the importance of being adapted to darkness prior to and during nighttime aircraft carrier operations were received from 71 experienced naval aviators. Analysis of their responses showed that, generally, their

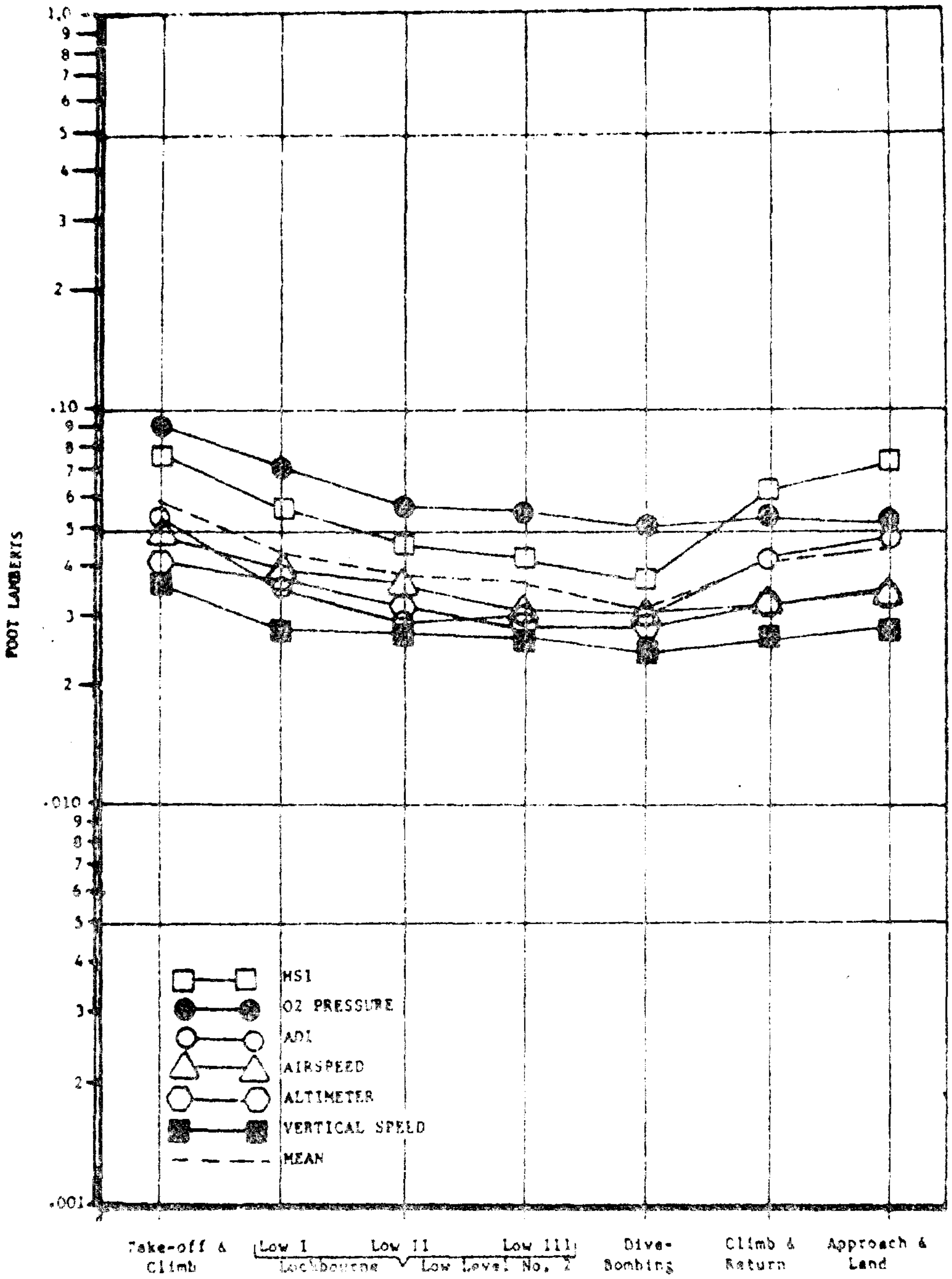

Figure 6. Average illumination used for displays as a function of flight segment (from DeBruine and Milligan).

opinion of the usefulness of dark adaptation is an individual matter. If the aviator had ever experienced its need, he was likely to be concerned". Although good dark adaptation would intuitively seem to be an asset for nighttime carrier operations, unfortunately, hard data are not available to either confirm or deny this supposition. Thus, nighttime carrier operations cannot be specifically called out as a basis for selecting (or rejecting) red interior lighting. This is particularly true since the introduction of white carrier deck lighting.

When all is said and done, the interaction between interior cockpit lighting color and mission requirements cannot be better defined than it is in the conclusion of a report by Smith and Goddard, 1967, who stated after an extensive review of the aircraft lighting literature: "Although much additional research is required in order to provide definitive answers regarding illumination of aircraft displays for night flight, the following general guidelines appear reasonable, based upon existing data: (1) In those few cases where mission requirements demand a maximum level of pilot dark adaptation, consideration should be given to the use of red lighting for cockpit displays. (2) For missions requiring less stringent dark adaptation requirements, the use of any color display illumination is acceptable". Thus, the decision as to whether the missions assigned to a given system impose sufficient nighttime out-the-window visual demands upon the pilot to warrant the use of red lighting still seems to rest upon those building, developing, and using the particular system in question (Milligan, 1970).

4. Visual Illusions. The tendency for instruments to disassociate themselves from the background and appear to "float" is a function of the level of luminance rather than hue. Since red lighting can be varied to the point of partial illumination of the background without seriously impairing dark adapation, it would appear to be preferred. However, this conclusion is valid only if maximum external nighttime vision is truly a requirement imposed upon the pilot by the aircraft's assigned missions.

5. Cost and Maintainability. No data were found which indicated a difference in "ruggedness" between white and red lighting. However, since the red lights, which have 90 percent of their output blocked by their red filters, are generally operated at higher voltage/current levels than white lights, it is reasonable to assume they would therefore have a slighly shorter average operational life. The MTBF of the red lamps is further reduced by the heat entrapment of their filters.

As currently implemented, white lighting systems are basically the equivalent of red lighting systems with the filters removed. Since the removal of filtration automatically results in a ten-fold increase in luminous flux, the intensity of the white lamps must be reduced to the basic nighttime range of .001 to .1 foot lambert (Dohrn, 1967, 1968) by dropping the voltage across a variable resistance and dissipating the excess power as heat. Thus, the basic power demands of present white light systems do not markedly differ from those of red light systems. However, were white lighting systems developed using currently available small, low voltage (1 volt), bulbs which do not require extreme attenuation, savings in lighting power load as large as 80 percent could be realized.

Where CRT displays are used, the placement of red filters over these displays does indeed impose a severe power drain. The phosphor to be used in the F-18 is P-43 with a peak spectral output in the 550 millimicron area (Moore, 1975). Since only a small fraction of this phosphor's light output is in the range transmitted

by red filters, the overall brightness of the CRT's and hence, the power demands are greatly increased as is the heat load requiring dissipation. If the CRT's are left unfiltered, their light output occurs at the point of maximum sensitivity for the cones (figure 2) which would appear to negate any reason for the use of red instrument lighting to protect these receptors from light adaptation. However, the study of the Kaiser FP-50 CRT Flight Display (Stowell, et al, 1970) revealed that "the white light of the display had negligible effects upon dark adaptation and visual acuity when operated at suitable low-level brightness for night-flight". In addition it was found that, at these low levles of luminance red filters served to "enhance contrast of the display by three or four times". Thus it cannot be said that CRT displays have no place in night-flight. Properly formatted, they may well replace so many dedicated control and/or display subsystems that the net result would be a savings in overall power demand and heat output. What is apparent is that no hard and fast generalities can be stated about the trade-offs between CRT use and night vision; each weapon system must be individually evaluated.

6. Pilot Workload. The ease of red lighting for nighttime operations may pose a transfer of training problem in that the pilot is now required to view red legends against a dark background instead of the white legends used for daylight flight. In addition, the pilot must extend his visual scan to be more attentive to warning signals since these are less visible under red illumination. Lastly, the longer the wavelength of illumination, the more stringent the demands upon the eye's accommodation system which could increase visual fatigue under red light, particularly for older pilots (Kamchatnov, 1969).

7. Visual Environment Evaluation. This is really to state the obvious that the cockpit designer should not become so involved in one aspect of his design problem that he forgets that the airplane he is designing flies in a multitude of real world situations. Thus, the argument for red light for carrier launch is probably purely academic for the Number 2 pilot who has just been staring into his lead's afterburner(s). The same could be said for the circumstances following a night rocket launch and, since the F-18's guns are on the top of the nose cone, perhaps after night gun fire as well. Red light is less effective during bad weather penetrations involving lighting since it takes longer to readapt to red light than to white which contains the portion of the spectrum to which the eye is most sensitive. The same would hold for exposure to nuclear flash. The presence of white flood lights helps compensate for these circumstances but only if the floodlight system is actuated prior to exposure. Wilcox and Cole, 1952, found that flight under starlit night sky conditions significantly degraded pilot dark adaptation independent of the type of lighting used. In short, there are many conditions, from starlight, warning lights, weapons flash, flare drops, to jet glow which can upset even the best concepts in internal lighting (Poston, 1974). Though rapid occlusion goggles, currently under development by NAVAIR, might protect against weapons flash as well as nuclear blast, the basic problem of external disruption of the pilot's dark adaptation still exists.

SUMMARY

As indicated above, both white and red cockpit lighting have their merits and their disadvantages. A summary comparison of these is compiled in table I. Unfortunately, the process of selecting a lighting system is more complicated than just counting the relative number of plus marks. It is clear that all of

TABLE I

RELATIVE ADVANTAGES OF RED VERSUS WHITE COCKPIT LIGHTING

	Red	White
Dark Adaptation (External Vision)	+	-
Low Illumination Acuity	+	-
Internal Depth Perception	-	+
Luminance Contrast	+	(-)
Luminance Uniformity	+	(-)
Chart Usage	-	+
Warning (Caution) Light Detection	-	+
Reflection/Glare Control	+	-
Detection of Internal Peripheral Lighting	-	+
Fatigue/Comfort	(-)	(+)
Cooling Load	-	+
Electrical Power Demand	-	+
CRT Display Compatibility	-	+

\+ Advantage

\- Disadvantage

(+) or (-) Operationally Reported

these variables should not contribute equally to the decision process. However, the relative weightings for these factors can be a source of almost unending discussions and would most likely differ between weapons systems based upon specific system requirements. This is not to say that no basis for decision can be formulated in the case of the F-18. However, to come up with a rationale for choice, we must accept certain assumptions, namely:

1. Night operations will indeed be conducted by the F-18.

2. Maximum out-the-window visibility (optimum dark adaptation) remains a valid requirement during at least some phases of these operations (see Appendix A)

3. The F-18 missions will be relatively short in duration (approximately 2 hours), thus visual fatigue can be discounted.

4. The final phase of both intercept and air-to-ground strike will use a guidance display format other than either hand held charts or a moving map display; also that no color coding of the E-O display formats is contemplated.

5. The added cost of red filtration is tolerable to the Program Manager.

6. The added electrical load and heat dissipation requirements of red lighting can be tolerated by the systems engineers.

7. The pilot will have the time to readapt after catapult (particularly if he is No. 2), after rocket release, and/or gunfire, prior to periods of maximum external nighttime visual demands.

If all these assumptions can be accepted as fact and not just an agenda for trade off discussions, then it would appear that the F-18 cockpit should be red lighted. This recommendation is based on the philosophy that if the F-18 is red lit and does not need to be, the penalties incurred are relatively minor (pilot fatigue, increased difficulty in map reading and warning detection, degradation of internal depth perception and peripheral light detection, increased power demand and cost), and not necessarily related to mission success and/or safety of flight. However, if you put in white light and the slight increment in dark adaptation achieved by red lighting proves to be a real requirement, the ability of the overall weapons system to <u>safely</u> perform all its assigned missions could be seriously degraded. It should be kept in mind, however, that practically every single one of the assumptions upon which this conclusion is based, has been questioned by both subjective opinions and conflicting data. Hence, we wind up with the same position with which we started: "If you really need the slight advantage of red light dark adaptation, you should have it". The question which must still be answered is:

DOES THE F-18 PILOT <u>REALLY</u> NEED MAXIMUM DARK ADAPTATION?

REFERENCES

Baber, K.E. Some Variables Influencing Vernier Acuity, J.O.S.A. 1949.

Brown, J.L. Review of the Cone-to-Rod Efficiency Ratio as a Specification for Lighting Systems. WADC Technical Report 57-448, August 1957.

Brown, K.T. and Grether, W.F. The Effects of Pure Red and Low Color Temperature White instrument Lighting upon Dark Adapted Visual Thresholds. WADC-6470 1952.

Burns, N.M. and Ziegler, R.B. Environmental Requirements of Sealed Cabins for Space and Orbital Flights. TEDNAM RE-1403, 22 July 1960.

Cavonius, C.R. and Hilz, R. Visual performance after Preadaptation to Colored Lights. J. Exp. Psychol. 83: 3-1, March 1970.

Chapanis, A. and Halsey, R.M. Luminance of Equally Bright Colors. ONR/JHU R-166-1-88, ONR, January 1955.

Chisum, G.T. Color Discrimination and Chart Reading under Red and Low Intensity White Light. AGARD, CP-26, October 1967.

Crook, M.N. Aeronautical Charts under Red Light. WADC-TR-54-198, WPAFB, May 1954.

DeBruine, C.J. and J.R. Milligan. In-Flight Test Results on Mission Oriented Cockpit Requirements. AFFDL-TR-71, WPAFB, September 1971.

Dohrn, R.H. Luminance Measurements for Red and White-Lighted Aircraft Instruments. AGARD, CP-26, October 1967.

Dorhn, R.H. Near Visual Acuity under Low-level Red and White Light. SAM TR-68-119, October 1968.

Farnsworth, D. and Hillmann, B. A Comparison of Specifications for Dark Adaptation Red. Medical Research Laboratory Report No. 219, 2 Feb 1953.

Grether, W.F. and Reynolds, H.N. The Effect of Red vs White Lighting on Dark Adaptation using a Simulated Instrument Panel for Preadaptation. AGARD CP-26, October 1967.

Hartline, H.K., et al. Tests on the Impairment of Pilot's Night Vision due to Illuminated Instrument Panels: Report No. 4. Committee on Aviation Medicine National Research Council, Washington, D.C. March 1941.

Hecht, S. and Hsia, Y. Dark Adaptation following Light Adaptation to Red and White Lights. J.O.S.A. 35: 261-267, 1945.

Hulbert, E.O. Time of Dark Adaptation after Stimulation by Various Brightnesses and Colors. J.O.S.A. 1951.

Intano, G.P. Legibility of Various Sized letters under Aviation Red, "[illegible]nar" White, and Neutrally Filtered Incandescent White Lighting Systems. AGARD, CP-26, October 1967.

Kamachatnov, V.P. Effect of Working in Red Light on Development of Fatigue. J. Indust. Med. 28: 12, December 1968.

Kennedy, R.S. and Berghage, T.E. Pilot Attitudes on Dark Adaptation and Related Subjects. Naval School of Aviation Medicine, Report 65-4, June 1965.

Luria, S.M. and Shartz. Visual Acuity under Red vs. White-Illumination. MRL Report 236, 14 January 1960.

Milligan, J.R. A Survey of United States Air Force Pilot Opinion on Cockpit Lighting. AFFOL Technical Report, TR-70-13, May 1970.

Moore, J., MACAIR. Telcom with L. Hitchcock, NADC, 4023, 8 July 1975.

Oesterberg, G. Topography of the Layer of Reds and Cones in the Human Retina. Acta Ophthal. Suppl., 61, 1-102, 1935.

Poston, A.M. A Literature Review of Cockpit Lighting. Human Engineering Laboratory, Aberdeen, AMCMS, 612106.11.A5500, T.M.-10-74, April 1974.

Reising, J. AFFDL/FDG Telcom with L. Hitchcock, NADC, 4023, 3 July 1975.

Reynolds, R.N. The Visual Effects of Exposure to ElectroLuminescent Instrument Lighting. Human Factors, 13 (1), 1971.

Rowland, W.M. and Aloan, L.L. The Relative Merits of Red and White Light of Low Intensity for Adapting the Eyes to Darkness. J.O.S.A. 1944.

Smith, H.A. and Goddard, C. Effects of Cockpit Lighting Color on Dark Adaptation. AFFDL, WPAFB TR-67-56, May 1967.

Stowell, H.R., Florio, D.J. and Bauer, R.W. FP-50 Flight Display Effects on Vision. Tech. Note 2-70, U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, March 1970.

Webster, A.P. and Lee, R.H. Report on the Influence of Brightness of Red and White Preadapting Lights on the Course of Dark Adaptation. National Research Council, Report No. 46, 25 March 1942.

Wilcox, R. and Cole, E.L. The Effect of Two Instrument Lighting Systems on Dark Adaptation. WADC TR-52-263, December 1952.

APPENDIX A

In order to obtain some current data on night vision requirements and pilot opinion regarding red light, the attached questionnaire was prepared and submitted to a number of operational units (see Acknowledgments). The following qualitative summaries are given to convey the general nature of the responses:

NAS, OCEANA

Oceana flight personnel reported red to be more difficult to read than white. They stated a perference for red during such missions as CAP and Air-to-Ground Attack. However, a majority reported that white would be acceptable for take-off, landing, and transit. Indeed, a number of respondents expressed a desire for both Red and White to be available for pilot selection.

VX-4

In contrast to the Oceana results, the VX-4 pilots overwhelmingly prefer Red for carrier recovery. They also listed rendezvous as a mission segment requiring Red lighting. One respondent mentioned a severe problem in reading thumb-wheel digits under red light.

NATC

The pilots from the NATC showed a 75 percent preference for white light but an equal percentage said it would be unacceptable for air-to-ground attack. Two NATC pilots reported using their VDI without a filter and that it had little or no effect upon their night vision when turned down to proper level.

NAS, MIRAMAR

The pilots responding from Miramar expressed a general preference for Red lighting with 75 percent stating they would not like White lighting under any flight condition. One pilot reported flying with an unfiltered VDI and stated that it had seriously degraded his night vision.

GENERAL

Across all respondents, the following general statements hold:

1. Approximately 25 percent of flight operations are conducted at night.

2. Approximately three-fourths of the pilots felt there was no basic difference between day and night operations. The remaining one-fourth felt that though the missions were the same, procedures often differed in the interest of safety.

3. In general, the pilots felt that full dark adaptation was necessary for:

a. Locating Surface Targets
b. Carrier Recovery
c. Sometimes for landing on a land base

4. In general, the pilots did not feel that full dark adaptation was required for:

a. Locating an Airborne Target
b. Taking off from a land base
c. Taking off from a carrier

5. The majority of pilots of all groups except NATC preferred red light. NATC expressed a 75 percent preference for white. This might well be the result of the fact that the NATC personnel had much more experience with white lit cockpits than did the other respondents.

6. In general, the pilots stated that:

a. White light was less fatiguing (a few felt quite the opposite)
b. Red light maintains dark adaptation better (unanimous)
c. White light is easier to read (92 percent)
d. Red light is more annoying (75 percent)
e. White light is more uniform in brightness (90 percent)

RED VS. WHITE COCKPIT LIGHTING

We at NAVAIRDEVCEN are currently involved in the development of the F-18. As part of this effort, we are looking at the relative advantages and disadvantages of red and white cockpit lighting. In order to provide us with fleet feedback on red lighting in the F-14, we would like you to answer the following questions:

1. Besides maintaining dark adaptation, do you feel there is any other reason for preferring red lighting over white lighting?

(a) Yes (state reason ______________________________)
(b) No

Remarks:

2. Would you prefer to have white cockpit lighting instead of the present red?

(a) Yes
(b) No

Remarks:

3. Are there any conditions under which you would <u>not</u> like to have <u>white</u> lighting?

(a) Yes (state condition ______________________________)
(b) No

Remarks:

4. Are there any conditions under which you would <u>not</u> like to have <u>red</u> lighting?

(a) Yes (state condition: ______________________________)
(b) No

Remarks:

5. What percent of your flight time is performed at night?

__________%

Remarks:

6. Do your day missions vary in nature from your night missions?

(a) Yes (explain: ______________________________)
(b) No

7. How often do you require maximum dark adapted night vision?

(a) Frequently
(b) Infrequently
(c) Depends on conditions (state conditions:__________________________)

Remarks.

8. How often do you require full dark adaptation for navigation?

(a) Frequently
(b) Infrequently
(c) Depends on conditions (state conditions:__________________________)

Remarks:

9. What reference points do you use for out-the-window navigation at night?

State reference points:_________________ ___________________________)

Remarks:

10. Do you feel that dark adaptation is required for out-the-window navigation at night?

(a) Yes
(b) No

Remarks:

11. How often would you use full dark adapted night vision for performing the following:

(a) Locating a surface target (state frequency: ______________________)
(b) Locating an airborne target (state frequency:______________________)
(c) Taking off from a land base (state frequency:______________________)
(d) Landing on a land base (state frequency: ______________________)
(e) Launching from a carrier (state frequency: ______________________)
(f) Recovery by a carrier (state frequency:______________________)

Remarks:

12. Do you feel that dark adaptation is necessary for:

(a) Locating a surface target? ______________________
(b) Locating an airborne target? ______________________
(c) Taking off from a land base? ______________________
(d) Landing on a land base? ______________________
(e) Launching from a carrier? ______________________
(f) Recovery by a carrier? ______________________

Remarks:

13. Rank the following by how much you feel you need dark adaptation to perform them (1 for need it most, 7 for need it least or not at all)

(a) Navigation _______
(b) Locating a surface target _______
(c) Locating an airborne target _______
(d) Taking off from a land base _______
(e) Landing on a land base _______
(f) Launching from a carrier _______
(g) Recovery by a carrier _______

Remarks:

14. Have you ever used your VDI without a red filter at night?

(a) Yes
(b) No

Remarks:

15. If your answer to 14 was yes, estimate the effect this had on your dark adaptation.

(a) No effect
(b) Little effect
(c) Great effect

Remarks:

16. Have you ever flown at night in a white lighting environment?
(a) Yes
(b) No

Remarks:

If your answer to question 16 is yes, please answer the following:

17. State the type of aircraft ____

Remarks:

18. Which environment do you prefer?

(a) White lighting
(b) Red lighting

19. Which of the following statements do you feel applies to red or white lighting?

(a) _______ is less fatiguing
(b) _______ maintains dark adaptation better
(c) _______ is easier to read
(d) _______ is more annoying
(e) _______ is more uniform in brightness

D I S T R I B U T I O N   L I S T

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